International Journal of Civil, Structural,
Environmental and Infrastructure Engineering
Research and Development (IJCSEIERD)
ISSN(P): 2249-6866; ISSN(E): 2249-7978
Vol. 4, Issue 2, Apr 2014, 103-110




# COMPARISON, INTER RELATIONSHIP AND RECALIBRATION OF MODIFIED PENMAN METHOD WITH PENMAN-MONTEITH METHOD

**K. CHANDRASEKHAR REDDY**

Professor & Principal, Department of Civil Engineering, Siddharth Institute of Engineering & Technology, Puttur, Andhra Pradesh, India

## ABSTRACT

This study deals with the evaluation of monthly reference evapotranspiration ($ET_0$) estimation using FAO-24 Modified Penman (MP) method by comparing its performance with that of FAO-56 Penman-Monteith (PM) method, developing relationship between MP and PM methods and recalibrating the method with respect to PM method. Tirupati region of Andhra Pradesh, India is selected as the study area and its meteorological data was collected from the India Meteorological Department, Pune. During comparison, it is observed that the percentage deviations of $ET_0$ values estimated by MP method with reference to PM method are significant. Even after developing inter-relationships between PM and MP methods, the performance is not satisfactory. Therefore, it is recalibrated with respect to PM method. The recalibrated MP method yielded the least RMSE and high $R^2$ & EC values resulting in $ET_0$ comparable with that from PM method. The MP method performed well in terms of performance evaluation criteria. The slope and intercept respectively close to one and zero also indicate an improved performance of the method with recalibrated coefficients. Therefore, recalibrated MP method may be recommended for reasonable $ET_0$ estimation in the study area.

**KEYWORDS:** Modified Penman, Penman-Monteith, Recalibration, Reference Evapotranspiration

## INTRODUCTION

Evapotranspiration (ET) estimation is vital in irrigation system design, crop yield simulation and water resources planning and management. Field measurement of evapotranspiration is rarely available and actual crop evapotranspiration ($ET_c$) is usually calculated from reference evapotranspiration ($ET_0$) using the crop factor method, which consists of multiplying $ET_0$ with crop coefficients ($K_c$) to obtain $ET_c$ (i.e., $ET_c = ET_0 \times K_c$). Several reports on the estimation of $K_c$ are available. Doorenbos and Pruitt (1977) [3], Doorenbos and Kassam (1979) [2], Jensen et al. (1990) [5] and Allen et al. (1998) [1] have reported crop coefficients for many crops. These values are commonly used in places where the local data is not available.

It is desirable to have a method that estimates reasonably the $ET_0$. The amount of $ET_0$ is calculated by meteorological data based methods. However, choosing the best method for $ET_0$ estimation from the described methods is difficult. Therefore, the International Commission for Irrigation and Drainage and the Food and Agriculture Organization of the United Nations (FAO) Expert Consultation on revision of FAO methodologies for crop water requirements have recommended the FAO-56 Penman-Monteith (PM) equation, which was presented in Allen et al. (1998)[1], to be used as the standard method to estimate $ET_0$. Many researchers thereafter took it as a standard to modify other methods that required less input data.

Allen et al. (1998) [1] presented that the Penman method may require local calibration of the wind function to achieve satisfactory results. Kotsopoulos and Babajimoponlos (1997) [6] derived mathematical expressions that describe the parameters used for the calculation of the Penman reference evapotranspiration through a nonlinear regression procedure. Comparisons of these expressions to those found in the literature showed more reliable results. Hussein (1999) [4] compared Penman combination equations with measured ET data from a clipped grass lawn. The PM method gave the best agreement with measured data, followed by the FAO Penman and Penman-Watts-Hancock methods. The 1963 Penman method was the least satisfactory among the methods tested. However, its performance improved significantly when the saturation vapour pressure was calculated as the mean value at maximum and minimum air temperatures. Shah and Edling (2000) [9] evaluated PM, FAO-Penman and 1963 Penman combination models for their capabilities to predict rice ET using daily weather data. The PM (daily) method had a $R^2$ of 63.7% as compared with 62.9, 60.0 and 61.7% for PM (hourly), FAO Penman and 1963 Penman methods respectively.

The present study reports the performance evaluation of MP method based on its accuracy of estimation and development of inter-relationship between MP and PM methods and also recalibrated with reference to PM method for Tirupati region of Andhra Pradesh, India.

## MATERIALS AND METHODS

Tirupati region, located in Chittoor district of Andhra Pradesh, India, with global coordinates of $13^0$ 05'N latitude and $79^0$ 05'E longitudes, has been chosen as the study area. The meteorological data of the study area for the period 1992-2001 was collected from IMD, Pune. Data from 1992 to 1998 is used for the purpose of training the model and that of 1999 to 2001 for testing the model. The details of the methods selected for the present study are presented in Table 1.

**Table 1: Details of Reference Evapotranspiration Estimation Methods**

| Method | Basic Reference | Equation | Input Data | |
|---|---|---|---|---|
| | | | Primary | Secondary |
| FAO-56 Penman-Monteith (PM) Method | Allen et al., (1998)[1] | $ET_0 = \dfrac{0.408\Delta'(R_n' - G') + \gamma' \dfrac{900}{T_{mean}+273} u_2 (e_s' - e_a')}{\Delta' + \gamma'(1+0.34u_2)}$ | $T_{max}$, $T_{min}$, $RH_{max}$, $RH_{min}$, $u_2$, n | .... |
| FAO-24 Modified Penman (MP) Method | Doorenbos and Pruitt (1977) [3] | $ET_0 = C\left[\dfrac{\Delta}{\Delta+\gamma} R_n + \dfrac{\gamma}{\Delta+\gamma}(0.27)(1.0+0.01U_2)(e_s - e_a)\right]$ where $C = 0.68 + 0.0028\,(RH_{max}) + 0.018\,(R_s) - 0.068\,(u_d) + 0.013\,(u_d / u_n) + 0.0097\,(u_d)(u_d/u_n) + 0.000043\,(RH_{max})\,(R_s)\,(u_d)$ | $T_{max}$, $T_{min}$, $RH_{max}$, $RH_{min}$, n | $u_2$, $u_d/u_n$ |

## PERFORMANCE EVALUATION CRITERIA

The performance evaluation criteria used in the present study are the coefficient of determination ($R^2$), the root mean square error (RMSE), systematic RMSE, unsystematic RMSE and the efficiency coefficient (EC).

### Coefficient of Determination ($R^2$)

It is the square of the correlation coefficient (R) and the correlation coefficient is expressed as

$$R = \frac{\sum_{i=1}^{n} (o_i - \overline{o})(p_i - \overline{p})}{\left[ \sum_{i=1}^{n} (o_i - \overline{o})^2 \sum_{i=1}^{n} (p_i - \overline{p})^2 \right]^{1/2}}$$

Where O and P are observed and estimated values, $\overline{O}$ and $\overline{P}$ are the means of observed and estimated values and n is the number of observations. It measures the degree of association between the observed and estimated values and indicates the relative assessment of the model performance in dimensionless measure.

**Root Mean Square Error (RMSE)**

It yields the residual error in terms of the mean square error and is expressed as (Yu et al., 1994) [10]

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (p_i - o_i)^2}{n}}$$

**Systematic RMSE ($RMSE_s$)**

It measures the room available for local adjustment. It is expressed as

$$RMSE_s = \sqrt{\frac{\sum_{i=1}^{n} (\hat{p}_i - o_i)^2}{n}}$$

Where $\hat{p}_i = a + bo_i$, a and b are the liner regression coefficients

**Unsystematic RMSE ($RMSE_u$)**

It shows the noise level in the model and is a measure of scatter about the regression line and potential accuracy. It is expressed as

$$RMSE_u = \sqrt{\frac{\sum_{i=1}^{n} (p_i - \hat{p}_i)^2}{n}}$$

**Efficiency Coefficient (EC)**

It is used to assess the performance of different models (Nash and Sutcliffe, 1970) [8]. It is a better choice than RMSE statistic when the calibration and verification periods have different lengths (Liang et al., 1994) [7]. It measures directly the ability of the model to reproduce the observed values and is expressed as

$$EC = 1 - \frac{\sum_{i=1}^{n} (o_i - p_i)^2}{\sum_{i=1}^{n} (o_i - \overline{o})^2}$$

A value of EC of 90% generally indicates a very satisfactory model performance while a value in the range 80-90%, a fairly good model. Values of EC in the range 60-80% would indicate an unsatisfactory model fit.

## RESULTS AND DISCUSSIONS

Comparing, developing inter-relationship and recalibrating the MP method with respect to PM method.

### Comparison between MP Method and PM Method

The percentage deviations of $ET_0$ values estimated by MP method with reference to PM method are 11.1 to 36.2. The deviations are significant. Fig.1 showing the comparison of $ET_0$ estimates with those of PM $ET_0$ also exhibit similar observations

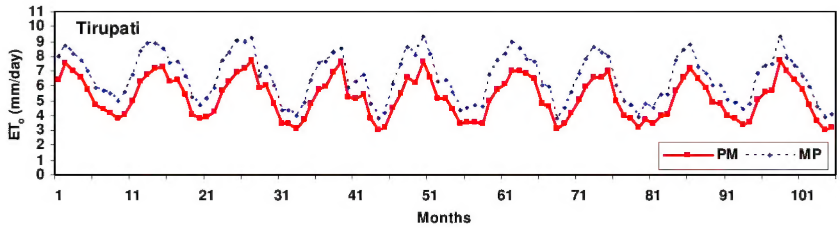


**Figure 1: Comparison of Monthly Average $ET_0$ Values Estimated by MP Method with Reference to PM Method**

### Development of Inter-Relationship between MP Method and PM Method

The $ET_0$ values estimated using MP method plotted against PM $ET_0$ are shown in Figure 2. The performance indicators of the relationship developed between PM and MP methods are presented in Table 2. Reasonably high $R^2$ values indicate a strong correlation between PM $ET_0$ and MP $ET_0$ values. This may be due to the fact that both the methods are physically based (combination) and require similar climatic parameters for $ET_0$ estimation. But large deviations of the slope from one and intercept from zero indicate the unsatisfactory performance of relationships between PM and MP method. And also, the considerable magnitude of unsystematic RMSE indicates the requirement of further dampening of noise level in the method represent the scope for recalibration. Therefore, it may be tried to improve this method's performance by suitably recalibrating it against PM method using the observed climatic data.

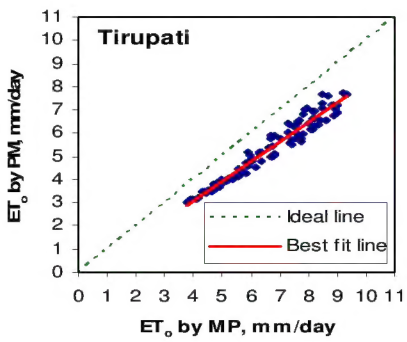


**Figure 2: Scatter Plot of Monthly Average $ET_0$ Values Estimated by MP Method against PM Method**

**Table 2: Performance Indicators of MP Method with Reference to PM Method**

| Method | Relationship | $R^2$ | RMSE (mm) | $RMSE_S$ (mm) | $RMSE_U$ (mm) | EC (%) |
|---|---|---|---|---|---|---|
| MP | PM = 0.8405MP – 0.2833 | 0.9536 | 0.29 | 0.06 | 0.29 | 95.36 |

**Recalibration of MP Method with Reference to PM Method**

It has been emphasized in the above section that MP method selected for the present study has not performed satisfactorily in the regional $ET_0$ estimation. The relationship developed between PM method and this method to estimate $ET_0$ showed an unsatisfactory performance in terms of RMSE. Therefore, it is recalibrated with respect to PM method.

The recalibrated equation derived for the study area is presented along with original equation in Table 3. The performance indicators of recalibrated equation in the estimation of $ET_0$ for both training and testing periods are given in Table 4. The scatter and comparison plots of $ET_0$ values estimated by this method with reference to PM $ET_0$ during the testing period are shown in Fig.3 and Fig.4 respectively.

It may be observed from Table 4 that the MP method yielded the least RMSE and high $R^2$ & EC values resulting in $ET_0$ comparable with that from PM method. The regression coefficients of scatter plots close to one and zero also indicate considerable dampening of noise level in the equation with recalibrated coefficients by decreasing the scatter about the regression line.

From the above discussion, it may be concluded that the MP method with recalibrated coefficients may be used for reasonable $ET_0$ estimation in the study area.

**Table 3: Recalibrated MP Equation**

| Method | Original Equation | Recalibrated Equation |
|---|---|---|
| FAO-24 Modified Penman (MP) Method | $ET_0 =$<br>$C \left[\frac{\Delta}{\Delta+\gamma} R_n + \frac{\gamma}{\Delta+\gamma}(0.27)(1.0+0.01U_2)(e_s - e_a)\right]$<br>Where<br>$C = 0.68 + 0.0028\ (RH_{max})$<br>$+ 0.018\ (R_s)$<br>$- 0.068\ (u_d) + 0.013\ (u_d / u_n)$<br>$+ 0.0097\ (u_d)(u_d/u_n)$<br>$+ 0.000043\ (RH_{max})\ (R_s)\ (u_d)$ | $ET_0 =$<br>$C \left[\frac{\Delta}{\Delta+\gamma} R_n + \frac{\gamma}{\Delta+\gamma}(0.27)(1.0+0.01U_2)(e_s - e_a)\right]$<br>Where<br>$C = 0.96 - 0.00119\ (RH_{max})$<br>$- 0.0108\ (R_s)$<br>$- 0.045\ (u_d) + 0.013\ (u_d / u_n)$<br>$+ 0.0097\ (u_d)(u_d/u_n)$<br>$+ 0.000032\ (RH_{max})\ (R_s)\ (u_d)$ |

**Table 4: Performance Indices of Recalibrated MP Method**

| Method | Slope of the Scatter Plots | | Intercept of the Scatter Plots | | $R^2$ | | RMSE (mm) | | EC (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Training Period | Testing Period | Training Period | Testing Period | Training Period | Testing Period | Training Period | Testing Period | Training Period | Testing Period |
| MP | 1.0084 | 1.0077 | -0.0420 | -0.0490 | 0.9976 | 0.9970 | 0.07 | 0.07 | 99.76 | 99.70 |

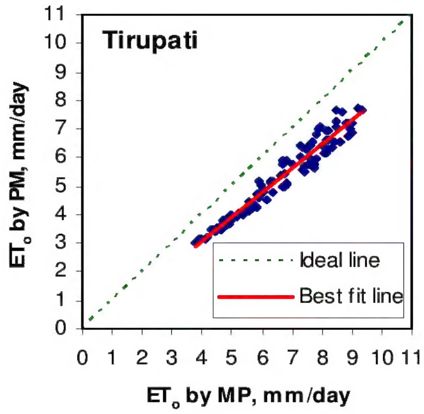


**Figure 3: Scatter Plots of Monthly Average $ET_0$ Values Estimated by Recalibrated MP Method against PM $ET_0$ Values during Testing Period**

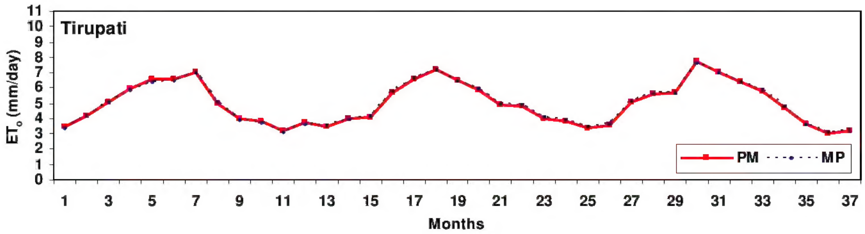


**Figure 4: Comparison of Monthly Average $ET_0$ Values Estimated by MP Method with Reference to PM Method during Testing Period**

## CONCLUSIONS

The percentage deviations of $ET_0$ values estimated by MP method with reference to PM method are significant. The MP method has not performed well even after developing inter-relationship with PM method. The MP method improved its performance significantly on recalibration. The recalibrated MP method performed equally well with PM method. Therefore, recalibrated MP method may be recommended for reasonable $ET_0$ estimation in the study area.

## REFERENCES


1. Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998), Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAO, Rome.
2. Doorenbos, J. and Kassam, A.H. (1979), Yield Response to Water. FAO Irrigation and Drainage Paper No 33. Rome, Italy.
3. Doorenbos, J. and Pruitt, W.O. (1977), Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper No.24. FAO, Rome, Italy.
4. Hussein, A. S. A. (1999), Grass ET estimates using Penman-type equations in central Sudan. Journal of Irrigation and Drainage Engineering, ASCE, Vol.125, No.6, pp.324-329.
5. Jensen, M.E., Burman, R.D. and Allen, R.G. (1990), Evapotranspiration and Irrigation water requirements. ASCE Manuals and Reports on Engineering Practice, No 70, New York, pp.332

6. Kotsopoulos, S. and Babajimopoulos, C. (1997), Analytical estimation of modified Penman equation parameters. Journal of Irrigation and Drainage Engineering, ASCE, Vol.123, No.4, pp.253-256.

7. Liang, G. C., O-Connor, K. M. and Kachroo, R. K. (1994), a multiple-input single - output variable gain factor model. Journal of Hydrology, Vol.155, No.1-2, pp.185-198.

8. Nash, J. E. and Sutcliffe, J. V. (1970), River flow forecasting through conceptual models part I: A discussion of principles. Journal of Hydrology, Vol.10, No.3, pp.282-290.

9. Shah, S. B. and Edling, R. J. (2000), Daily evapotranspiration prediction from Louisiana flooded rice field. Journal of Irrigation and Drainage Engineering, ASCE, Vol.126, No.1, pp.8-13.

10. Yu, P. S., Liu, C. L. and Lee, T. Y. (1994), Application of transfer function model to a storage runoff process. In Hipel K.

11. W., McLeod A.I. and Panu U.S. (Ed.), Stochastic and Statistical Methods in Hydrology and Environmental Engineering, Vol.3, pp.87-97.